The Density of Niton ("Radium Emanation") and the Disintegration Theory.

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According to the disintegration theory of radioactive change, a definite number of atoms of radium break up per second, each evolving an α-particle which ultimately becomes a helium atom, leaving behind lighter molecules which form the gas known as "radium emanation," or niton. The identity of the α-particle after it has lost its electric charge with the helium atom has been convincingly proved by Rutherford and Geiger; and measurements of the volume of helium evolved from niton by Ramsay and Soddy, and from radium in equilibrium with its disintegration-products by Dewar, render it exceedingly probable that in each successive change from radium to radium D only one α-particle is expelled per atom.

If, then, the view is held that the radium atom on disintegration to niton splits up into two parts only, one of which is the α-particle, then the atomic weight of the resulting niton is $226{\cdot}4-4 = 222{\cdot}4$. On the other hand, it may be supposed that the disintegrating radium atom splits up into three or more parts; helium, and two other bodies of higher atomic weight, if three parts. On account of its greater mass, the heavier particle might be expelled below the critical velocity necessary for the formation of ions in the air, and might itself be non-radioactive; if this were the case, its presence in a solid state would almost certainly escape detection. There is no direct evidence against such a supposition, for the atomic weights of none of the products of the disintegration of radium have been determined. Experiment alone can settle this question of the true atomic weight of niton; but on account of the exceedingly small volume of this gas obtainable from a relatively large weight of radium, the experiment is by no means easy.

A number of investigators have sought to obtain the atomic or molecular weight by comparing the rates of diffusion of "emanation" and air or nitrogen.

Pierre Curie and Danne	found.........	176*
Bumstead and Wheeler	"	180†

* 'Comptes Rendus,' 1903, vol. 137, p. 1314.

† 'Amer. J. Sci.,' 1904, p. 97.

Rutherford and Miss Brooks found	....	176*
Makower "	....	100†
Chaumont "	....	70—100‡

Perkins compared the rate of diffusion with that of mercury vapour, also a monatomic gas, and found 235.§

Lastly, Debierne made use of Bunsen's method of causing the gas to issue through a minute perforation in a diaphragm of platinum, and as the result of a very concordant set of experiments, obtained the number 220 for the molecular weight.||

But none of these methods, however ingenious, can be accepted as conclusive, for the conditions are so different from those usually obtaining in ordinary work that no certain inference can be drawn.

In 1909¶ we attempted the solution of this problem in another way. We found it possible to determine the critical and boiling points of niton with less than one-tenth of a cubic millimetre of gas. Assuming it to belong to the inactive series of gases, we plotted the critical and boiling points of argon, krypton, and xenon against their atomic weights, and found these points to lie almost exactly on a slightly curved line. Extrapolation showed that for the emanation to lie either on the line connecting the boiling points or the critical points, it must possess an atomic weight approximating to 176. It was quite impossible to bring the value 222·4 anywhere near the extrapolated curves; but it must be observed that, as the curvature is slight, a small error in the constants of argon, krypton, or xenon might alter the curvature in the reverse direction, and so make more probable the higher atomic weight. We realised at the time that the results could not be accepted as certain, and that the only criterion must be the determination of the density of the gas. It is, however, remarkable that all the determinations quoted, with the exception of Makower's and Chaumont's, point to an atomic weight either of 176 or of 222; these are the tabular atomic weights of the immediate follower of xenon in the periodic table, on the one hand, and of the next member on the other. The members of the series are:—

Helium.	Neon.	Argon.	Krypton.	Xenon.	I.	II.
4	20	40	83	130	176	222

* 'Trans. R. S. Canada,' 1901.
† 'Phil. Mag.,' 1905.
‡ 'Le Radium,' 1909, vol. 6, p. 106.
§ 'Amer. J. Sci.,' 1908, p. 461.
|| 'Comptes Rendus,' 1910, vol. 150, p. 1740.
¶ 'Trans. Chem. Soc.,' vol. 93, p. 1073.

To determine the density of a gas, four separate measurements are essential—the volume, the temperature, the pressure, and the weight of the gas. In the present case, however, the problem was simpler, for the volume of niton at normal temperature and pressure accumulating in a given time from a known weight of radium is a constant and invariable quantity, and has been repeatedly measured. In 1908 Rutherford found this volume to be 0·61 cu. mm. per gramme of radium; Debierne in 1909 obtained the value 0·58 cu. mm., and these results were confirmed shortly afterwards by our own work,* which gave 0·601 cu. mm. Rutherford has been able to calculate this constant from the result of his beautiful experiment in which he actually counted the number of α-particles emitted from a known weight of radium, and the value found was 0·585 cu. mm. It may therefore be taken as certain that the error in this constant does not exceed 5 per cent. For our experiments this figure is unessential, since the actual volume of emanation from the total radium at our disposal had been measured.

The problem which we have attacked is the determination of the weight of emanation evolved in a given time from our total quantity of radium. The radium bromide solution from which the niton for these experiments was drawn was contained in three bulbs sealed on to a Töpler pump. The maximum measured quantity of emanation which can be extracted with the pump from the solutions in the bulbs is 0·127 cu. mm. By collecting the gas every eight days, the yield was only 76 per cent. of this quantity, so that the total volume obtainable for weighing scarcely exceeded 0·1 cu. mm. The weight of this volume, on the assumption that the atomic weight is 222, is less than 1/1400 mgrm. It is therefore evident that in order to weigh this minute quantity of gas with sufficient exactness, a balance turning with a load not greater than 1/100,000 mgrm. was a necessity. This seems an almost inconceivably small weight to attempt to measure, when one considers that the limit of sensibility of a delicate assay balance is about 1/200 mgrm., and that even the Nernst balance will hardly turn with a load smaller than 1/2000 mgrm.†

The successful construction of a balance capable of weighing these very minute quantities has been accomplished by Dr. B. D. Steele and Mr. Grant, of the University of Melbourne; thanks to their skill and ingenuity, they have constructed an instrument 100 times more sensitive than the Nernst micro-balance. Steele and Grant have published an account of their

* *Loc. cit.*, p. 1082.

† As we shall have to deal with very small weights, it is advisable to adopt a new unit; this is conveniently the millionth of a milligramme. The abbreviation here used for this is μmgrm.

balance,* and they have shown that a sensibility of 1/250,000 mgrm. could be attained. After several trials we have been successful in constructing a similar instrument and in determining the density of the radium emanation with its help. It is only fair to state, however, that Dr. Brill, working in the laboratory of University College, improved the Nernst balance, so that it turned with 1/10,000 mgrm. The subject was followed up later by Dr. Gwyer, also at University College, who introduced the hydrostatic method of determining small weights, the buoyancy of a small bulb containing a known weight of air being altered by the adjustment of the pressure in the balance case, constructed so that a vacuum could be made. We then corresponded with Dr. Steele, who was so obliging as to inform us of the principle and construction of his balance, then in an experimental stage.

The paper published by Steele and Grant renders a minute description of our balance unnecessary; but our balances (for several were constructed) differ in some small respects from theirs. The beam, for example, was made by placing thin silica rods in grooves carefully ruled on a smooth plane block of graphite, and then fusing the contiguous ends together in an oxygen coal-gas flame; in this way, a symmetrical beam, lying on a plane surface, was secured. If this condition is not fulfilled, the beam is apt to be deformed by small stresses set up in the quartz at the points of junction, as found by Steele and Grant. It is also necessary that the knife-edge shall be at right angles to the beam in two planes. This was managed by sealing the knife-edge on to the beam with a long guiding rod of silica attached to it, so that adjustment to a right angle is not difficult by trial and error; this guiding rod, when fused off, left a stem of a few millimetres in length, to which the platinised silica mirror was fused. By this device the mirror revolved without displacement when the balance was deflected. Another improvement was the direct sealing of a fine quartz fibre to the end of the beam, whereby a much freer suspension was attained. Again, while Steele and Grant weighed by displacement of the zero, our weighings were made by a null method, whereby the alteration of pressure brings the spot of light to its original position. In this way, any possible variation in the sensibility of the beam with its deflection from horizontality is avoided. To eliminate as far as possible temperature changes and also vibration, the balance is mounted on a stone pillar in a cellar, and the brass case stands inside a large box of bright tin-plate. The mirror is illuminated by a beam of light from a Nernst lamp, which reflects on to a millimetre scale about 3 metres away. The light is allowed to impinge on the mirror only when a reading is taken.

* 'Roy. Soc. Proc.,' A, 1909, vol. 82, p. 580.

The small counterpoise quartz bulb, which contains a known weight of air, serves instead of a set of weights. When the air pressure in the balance case is the same as that in the bulb the apparent weight of the air which it contains is nil. That is to say, the real weight of the air in the bulb is exactly counterpoised by the buoyancy of the air outside. In a vacuum the sealed-up air exerts its full weight, and at any intermediate pressure the arm of the beam carrying the bulb is loaded with a known fraction of this weight. The counterpoise bulb of the balance used by us has a capacity of 22·2 cu. mm., and the air which it contains weighs 0·027 mgrm., or 27,000 μmgrm. (millionth milligrammes). A pressure change of 1/10 mm. can be easily read by a cathetometer, so that any object lighter than 27,000 μmgrm. can be weighed with an accuracy of 3·55 μmgrm.

By reading the pressure more exactly, say to 1/100 mm., the limit of accuracy could have been increased to one-tenth of the figure above, provided, of course, that the sensibility of the balance is great enough; to obtain this maximum degree of sensibility two important conditions have to be fulfilled. The centre of gravity of the beam must be most carefully adjusted, and the knife-edge must be perfectly straight and regular, even when viewed through a microscope with a half-inch objective. The final adjustment of the centre of gravity is made by volatilising away from the top of the centre rod, round which the beam is built, minute quantities of quartz in the oxy-coal gas blowpipe; this is a comparatively simple process. The making of the knife-edge gave a good deal of trouble, but in the end this difficulty was overcome. The edge itself is about 0·3 or 0·4 of a millimetre long, and is ground in the form of a right-angled prism on the end of a quartz rod, which is subsequently fused on to the beam. The grinding and polishing of the edge, which is a very delicate operation, was carried out for us by Messrs. Hilger and Co.

Our present balance is sensitive to about 2 μmgrm.; its zero remains perfectly constant for days together. When the counterpoise bulb is removed, the zero of the balance is not altered by large changes of pressure within the case.

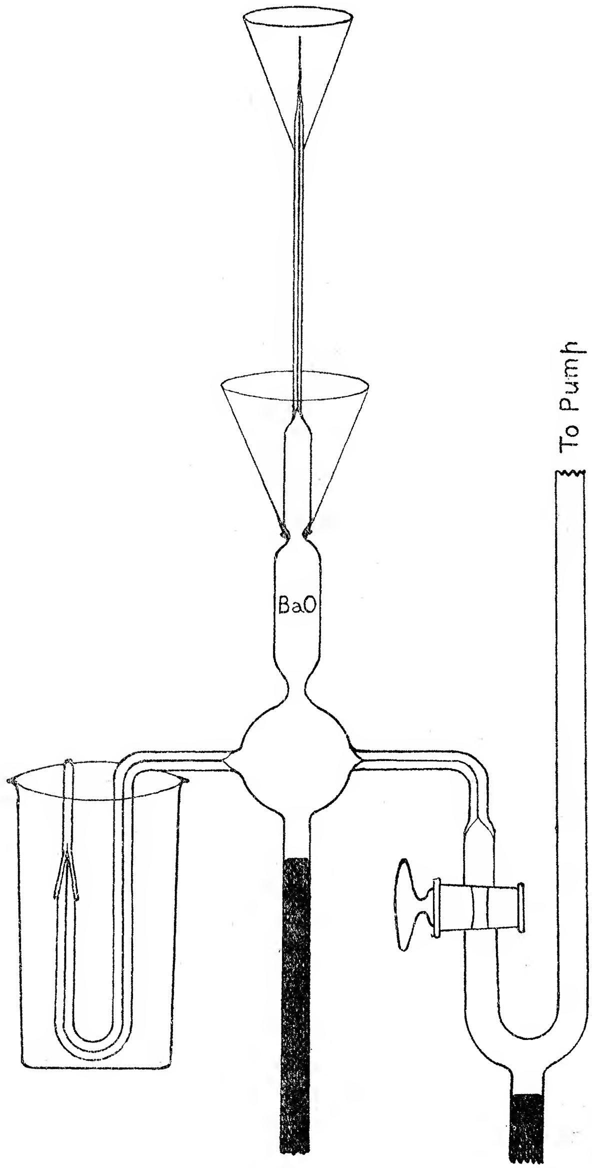
The standard of weight, which is, of course, the weight of the air in the counterpoise bulb, has been verified in the following way: A long measured length of very fine aluminium wire was weighed as accurately as possible on an assay balance. A small portion of this wire, about 2 mm. in length, was cut from the longer length in such a way that the cross-sections were as nearly as possible circular; it was then measured under a reading microscope, and its weight was determined in terms of the counterpoise-bulb on the micro-balance. The weight so determined agreed within 1 per cent.

with the weight calculated, on the assumptions that the wire was uniform, and that the weight of the small piece was directly proportional to its length.

For the measurement of the density of very small quantities of niton or of other gases, the following procedure was adopted:—The gas, of a volume of the order of 0·1 cu. mm., was forced by means of mercury into a fine capillary tube of about 1 mm. external and 0·2 mm. internal diameter, which was sealed on to the apparatus for purifying the gas (see figure). The upper end of this tube was drawn out into a finer very thin-walled tube, the extreme point of which was sealed. When necessary, the volume of the gas was measured at various pressures in the capillary tube, carefully calibrated for this purpose. After measurement, the tip of the tube was surrounded for some minutes with liquid air, in order to condense the gas; the volume of the gas was then considerably increased, so that any hydrogen still present should expand, and only a minute trace could remain at the top of the tube; the tube was then sealed at a distance of about 20 mm. below the tip, by aid of a pin-point gas flame. After most carefully cleaning and drying the small tube, it was lifted with platinum-tipped forceps, the tips of which had just been heated to redness, and placed in a little tightly-fitting "bucket," or external tube, of silica, suspended from one arm of the balance by quartz fibre; the pointed end of the density-tube was downwards, and the lower end of the bucket was slightly curved. A quartz counterweight, suspended to the same arm of the balance, was then adjusted, by fusing on or by volatilising off small pieces of silica, so that the beam was in balance at a pressure in the neighbourhood of 50 mm. After an hour or more the pressure in the case was exactly measured, and the position of the spot of light on the scale was noted. The bucket and tube were then removed with the platinum-tipped forceps; and, while it was held vertical inside a wider tube, the density tube was pressed down with a glass rod, cup-shaped at the end; the drawn-out point of the density-tube broke, but no splinters of glass could escape, for they were all retained in the bucket of silica. The bucket and its tube were then replaced on the balance and the air was exhausted; air was again admitted, and a second exhaustion was made; in this way the gas was removed from the interior of the density-tube, and replaced by air. The pressure was then adjusted to bring the zero point back again to its original position. With practice, the whole operation could be carried out in less than five minutes; this reduced the chance of error from the condensation of moisture on the glass and the settling of dust particles.

Before experimenting with the precious niton, the method was tested with

the less valuable xenon. Before freezing the gas its volume was measured; it amounted, at 0° and 760 mm., to 0·0977 cu. mm. It was then frozen, and the density-tube was sealed off and placed in its bucket on the



balance; after breaking the tip, the pressure change was 17·1 mm. (70 − 52·9); the temperature change was too small to affect the result; this pressure change corresponds to an apparent loss of weight of 608 μmgrm. But this number

does not represent the real weight of the xenon, for in the second weighing the tube is full of air, and therefore to the observed weight the weight of the air filling the tube at the temperature and pressure of the second weighing has to be added. The volume of the tube being known (for its length was measured), the weight of air under the conditions of weighing (52·9 mm. and 16°) proves to be 46 μmgrm.; hence the total weight is 654 μmgrm. A further correction has next to be applied to allow for the difference in buoyancy of the glass of the weighing-tube in the two weighings. This correction could, of course, be calculated, provided one knew the weight of the tube, the density of the quartz of the silica counterpoise on the end of the beam opposite to the objects to be weighed, and the density of the sample of glass forming the weighing-tube. It was found, however, to be more accurate and convenient to determine directly on the balance the magnitude of this correction for each experiment. For this purpose the counterpoise bulb containing air was replaced by a piece of quartz of almost exactly the same weight, and under the new conditions the variation of the zero point of the balance for a given change of pressure was determined. Knowing the weight corresponding to each scale-division displacement of the zero point, the variation in buoyancy of the open glass tube between the two weighings was easily and accurately calculated. In general, this correction is a somewhat large one, and amounts in this case to no less than one-seventh of the total weight of the gas. The reason for this is the large difference in weight between the density-tube and the contained gas. The density tube, as a rule, weighed about 30 mgrm., and the contained gas about 1/2000 mgrm.; hence the weight of the gas is to that of the vessel as 1 to 60,000, whereas, under ordinary conditions, when weighing 200 c.c. of gas, the ratio is about 1 to 600.

In this experiment, the correction for the buoyancy of the glass proved to be 91 μmgrm.; but there is still a correction to be applied, for there is a change of buoyancy due to the volume occupied by the gas itself. As the volume of the tube was known, this could be calculated with greater accuracy than it could be determined by experiment. In this case, the xenon occupied 0·536 cu. mm., and the difference in buoyancy of the air between the pressures 70 and 52·9 mm. (17·1 mm.) is

$$17{\cdot}1 \times 0{\cdot}536 \times 1{\cdot}29/760 \times 1000 = 15 \ \mu\text{mgrm.}$$

Had the sealed tube been weighed at the lower instead of the higher pressure (at 52·9 instead of 70 mm.), it would have weighed more; hence this correction is positive. The true weight of the xenon is therefore $654 - 91 + 15 = 578$ μmgrm. The calculated weight of 0·0977 cu. mm. of xenon is 577 μmgrm. The exact agreement is doubtless a coincidence.

With niton, two sources of error made their appearance; in the first place, the density-tube became strongly electrified, and attracted dust particles and adsorbed air, and in the second, the tube was always at a higher temperature than the surrounding atmosphere during weighing,* and convection currents were liable to be set up in the air surrounding one limb of the balance. The first of these effects could not be entirely eliminated, but it was considerably reduced as regards dust by filtering the air through a long column of tightly packed cotton-wool before allowing it to enter the balance-case. In addition, the tube, after suspension from the beam of the balance, was, as a rule, gently heated by passing a non-luminous pin-pointed gas-flame quickly over its surface, thus burning off most of the attracted particles of dust. The same expedient was also adopted, before the second weighing, after the tube had been broken. Blank experiments showed that this procedure did not alter the weight of the tube in the slightest degree, provided it was perfectly clean; when dust-particles were present, however, there was always a small loss of weight.

The effect of convection currents was reduced as much as possible by weighing at a low pressure; in our five experiments, the final pressure varied from 87 to 13 mm.; and the concordance of the results precludes the possibility of any serious error from this source. It may also be noted that the density-tube, after removal of the niton, and during the second weighing, contained approximately the equilibrium amount of radium A, B, and C, the heating effect of which is a large fraction of the total heating effect of the emanation in equilibrium with its quick-change products; hence any error in the first weighing was partially compensated by a similar error in the second weighing. Finally, we would point out that convection currents, on account of the position and shape of the tube, have very little influence on the balance, and their presence should have been revealed by the oscillations of the beam and the position of the zero-point. No irregularity, however, was noticed, and we believe that this source of error produced only negligibly small effects.

Before proceeding to cite the experimental results, we have still to explain how the exact volume of niton weighed was ascertained. Taking as a basis our previous measurements, which proved the equilibrium amount of niton yielded by the total amount of radium at our disposal to be 0·127 cu. mm. at normal temperature and pressure, we had to determine what fraction of this amount was actually present in our weighing-tube. This was conveniently done by measurement of the γ-ray activity by help of a small aluminium electroscope. The procedure was as follows:—

* See Ramsay, 'Trans. Chem. Soc.,' 1907, vol. 91, p. 931.

The emanation was drawn off from the radium-bulbs at definite intervals of time, usually eight or nine days. After explosion of the mixed oxygen and hydrogen gases, it was allowed to stand for several hours, so that the quick-change products should accumulate, and its γ-ray activity was measured in the usual way. It was next introduced into the density-tube, and frozen there, as described for xenon, and the hydrogen was removed by pumping; about 10 per cent. of the niton was pumped off with the hydrogen, for the niton has some vapour-pressure at $-195°$. The γ-ray activity of the gas removed was compared with that in the sealed-off density-tube, after a suitable interval of time. Other measurements were made to determine the quantity remaining in the purifying apparatus; but in most cases this was negligible, and, as a rule, the radioactivity of the pumped-off gas, *plus* the radioactivity of the gas in the weighing-tube, were together equal, after corrections for the decay had been made, to the initial total radioactivity of the gas before it had been purified. It was found, however, that some niton had entered the walls of the weighing-tube; this fraction was estimated by determining the radioactivity of the empty tube, immediately after it had been weighed. Obviously, this emanation had not been removed by the pump. In the table which follows, this amount appears in the column "volume left in tube"; it has been subtracted from the total volume.

The operations of drawing and purifying the emanation, measuring its radioactivity, counterpoising and weighing the density-bulb, and measuring the radioactivity of the amount pumped off, as well as that in the weighing tube, required a long day, so that the density-tube could not be broken until 24 hours after the niton was drawn; the actual volume of niton present at the moment of fracture, however, was easily calculated from its known rate of decay.

As the quick-change products A, B, and C are short lived and change rapidly into D, and as D is a solid, it remains in the density-bulb and is not weighed, but the helium resulting from the change of niton into A, A into B, and C into D, escapes for the most part along with the niton; its weight must be calculated, and that of the escaping gas diminished by its amount, in order to arrive at the true weight of the niton.

Five experiments were made in order to determine the total loss of weight on opening the density-tube, and a sixth to obtain an estimate of the weight of the helium produced by the disintegration of the niton as far as radium D. For this purpose a density-tube was filled as described in the middle of the month of July, 1910; it remained counterpoised on the balance until October, when the conversion into D was practically complete. As the half-life period of D is about 14 years, it is unnecessary to consider

any further change. At the end of October the point of the density-tube was broken as usual, and the tube was again weighed, the loss in weight being due to the helium produced.

We must here chronicle the fact that during the three months in which the tube hung on the balance a continuous gain in weight was noticed, rapid at first, but attaining an end point; this amounted to 670 μmgrm. On heating the tube, 1280 μmgrm. were lost. The tube had not been heated before it was originally suspended on the balance; the gain was probably due to condensation of air on the electrified surface, and possibly, but improbably, to the deposition of dust. This gain of weight on standing is, however, not confined to electrified surfaces; a gold capsule, heated to redness before suspension, gained considerably in weight for two days. The density-tube was heated and re-suspended on the balance, and for three hours there was no alteration of weight. It was then broken and immediately placed on the balance, and weighed within five minutes, during which it might be expected that no change would occur; the loss of weight was 15 μmgrm., The volume of the density-tube was 0·196 cu. mm.; the weight of air filling it at 37·7 mm. pressure and 18·5° C. was 12 μmgrm.; hence the total weight of helium was 27 μmgrm.; no correction for glass displacement of air was necessary, for the pressure did not vary during the readings.

The calculated weight of helium obtainable from 0·072 cu. mm. of niton, the amount present in the tube, on the assumption that each atom (or molecule) of niton loses three α-particles on disintegrating to RaD, should have been 38 μmgrm.; of this, only about three-quarters had been removed by the pump. It was necessary to seek for the remainder, which, we believed, had entered the glass of the weighing-tube.

Before removing it, however, we thought it worth while to attempt to dissolve the deposit of radium D from the walls of the weighing-tube, and to estimate its amount by loss. The closed end of the weighing-tube was cut off, and the rest of the tube placed in the bucket along with it, and weighed. The tube itself was then washed out with a mixture of two drops of nitric acid, previously purified by distillation from a silica bulb, and one of water; the solution was preserved. The tube was then washed with water and dried by aspirating through it a current of dry air; it was then replaced in the bucket and re-weighed. The loss was 831 μmgrm. Supposing that the emanation, the calculated weight of which, assuming it to have the atomic weight 222·4, was 713 μmgrm., had lost three α-particles, the weight should have been 674 μmgrm. The difference, as we have proved by a subsequent experiment on the solubility of glass in dilute nitric acid, is due to the removal of sodium and calcium as nitrates. This must have

amounted in the case given to $831-674=157$ μmgrm. We identified under the microscope crystals of sodium nitrate.

It is obvious that no importance can be attached to the latter half of this experiment, except in as much as it shows a loss of weight of the order required.

The weighing-tube still contained presumably occluded helium. It was placed in a silica tube, surrounded by a thicker-walled tube, also of silica, and it was connected with a Töpler pump and with an inverted siphon for introducing oxygen. The apparatus was freed from air and washed out several times with oxygen, so as to avoid introducing helium or neon from the air. About one-third of a cubic centimetre of oxygen was then admitted, and the silica tube was heated in a blow-pipe flame until the glass weighing-tube had completely fused; small bubbles were evolved. The oxygen, together with the gas evolved from the tube, was pumped off and introduced into an apparatus consisting of a calibrated capillary tube in communication with a minute bulb containing charcoal cooled with liquid air. After some hours the oxygen was completely absorbed by the charcoal, and the residual gas was measured. The correction for the unmeasured gas still remaining in the charcoal bulb was found to be 4 per cent. The volume was 0·042 cu. mm. at 0° and 760 mm. pressure, and its weight was therefore 8 μmgrm. The sum of the helium actually weighed (27 μmgrm.) plus that measured (8 μmgrm.) gives a total of 35 μmgrm., differing from the calculated amount (38 μmgrm.) by only 3 μmgrm. That the gas measured was pure helium was proved by surrounding the upper part of the capillary tube with tin-foil, and passing a discharge from a coil through it. The full spectrum of pure helium was seen, and no other lines.

This result has astonished us, as, perhaps, it may astonish our readers, but the conditions under which the last weighing was made were particularly favourable, since the tube was practically non-radioactive.

This experiment taught us that about one-quarter of the helium produced by the disintegration of the emanation and its products enters the walls of the weighing-tube, and is not removed by the pump; we have now all the data for calculating the density of niton. The results are given in the annexed table:—

Table of Results.

No. of experiment.	Time of accumulation.	Total volume of niton.	Volume pumped off.	Decay of niton.	Volume left in tube.	Volume weighed.	Apparent weight.	Weight of air replacing niton.	Correction for displacement due to glass and air.	Correction for weight of helium produced from niton.	True weight of niton.	Atomic weight of niton.
	Day.	Cu. mm.	Cu. mm.	Cu. mm.	Cu. mm.	Cu. mm.	Micro-mgrm.	Micro-mgrm.	Micro-mgrm.	Micro-mgrm.	Micro-mgrm.	
1	8	0·0969	0·0052	0·0182	0·0007	0·0728	721	+ 31	−29 + 24	− 8	739	227
2	9	0·1017	0·0188	0·0163	0·0100	0·0566	477	+103	−16 + 15	− 7	572	226
3	9	0·1017	0·0135	0·0253	0·0039	0·0590	577	+ 37	−22 + 9	−10	591	225
4	8	0·0969	0·0119	0·0157	0·0016	0·0677	673	+ 10	−26 + 12	− 6	663	220
5	8	0·0969	0·0082	0·0152	0·0005	0·0730	704	+ 29	−33 + 16	− 6	710	218
											Mean...	223

A complete reproduction of Experiment 5 may be given, to show how all the requisite data are obtained and utilised.

Volume of niton accumulated in 8 days = equilibrium quantity × fraction surviving .... 0·127 × 0·763 = 0·0969 cu. mm.
γ-ray activity of this sample, divisions per hour .... 3996 divisions.
γ-ray activity of fraction pumped off.................................. 353 „
Hence amount pumped off .... 0·0082 cu. mm.
Amount of niton in weighing-tube = 0·0969 − 0·0082 = ... 0·0887 „

The weighing-tube was then counterpoised on the balance.

Pressure in balance-case .... 54·4 mm.
Zero on scale of beam of light reflected from mirror .... 155 „

Twenty-five hours after drawing, the weighing-tube was broken.

The gas pumped out, however, was not the original 0·0887 cu. mm., but that volume multiplied by the decay-factor for 25 hours, 0·828, viz. .... 0·07347 cu. mm.
Pressure in balance-case after breaking the density-tube .... 34·7 mm.
Pressure-change = 54·4 − 34·7 .... 19·7 „
Zero on scale after breaking .... 154 „
Difference of zero = 155 − 154 = 1 mm. But from measurement, 10 mm. pressure = 77 scale divisions; hence 1 division = 10/77 = ... 0·13 „
This must be added to the pressure—19·7 + 0·13 = ... 19·83 „
The counterpoise-bulb contained 0·0270 mgrm., or 27,000 μmgrm. of air. Its buoyancy was altered by (19·83/760) × 27,000 = ... 703·8 μmgrm.

But air entered the tube when it was broken; the volume of the density-tube, ascertained by previous calibration, was 0·522 cu. mm.

Weight of this air at 34·7 mm. and 17° C. = 0·522 × 1290 × 35/760 × 273/290 = ... 29·2 μmgrm.
The sum of these quantities, 703·8 and 29·2 .... 733 „

But the pressure was changed by 19·8 mm.; this alters the weight of the density-bulb by the weight of air corresponding to the difference in volume between the glass density-bulb and a silica one; as already described, this quantity was determined directly by replacing the air-bulb by a solid counterpoise of silica, and using the density-bulb as a measure of buoyancy. For 19·8 mm. the "glass-displacement" is equivalent to $-32·8$ μmgrm. A further correction has to be made, viz. the change of buoyancy due to the volume occupied by the gas itself. The volume of the density-tube was 0·522 cu. mm.; the change of pressure was 19·8 mm.; hence the weight of this air for 19·8 mm. change $= 0·522 \times 1290 \times 19·8/760 \times 273/290 = 16$ μmgrm. This is a positive correction; the weight, 733 μmgrm., must be diminished by the difference between 32·8 and 16, say 17 μmgrm. The remainder is 716 μmgrm.

The last correction to make is the subtraction of the weight of the helium produced by the decay of the emanation during its stay in the weighing-tube. Now

22,400 cu. mm. niton weigh, say, 222·5 mgrm., and
0·0224 ,, ,, weighs ,, 222·5 μmgrm.

Each atom of niton gives three atoms of helium; hence, helium from 0·0224 cu. mm. niton weighs 12 μmgrm. The volume of emanation decayed in the weighing-tube is 0·0887 cu. mm. $-$ 0·0735 cu. mm. $=$ 0·0152 cu. mm., and the weight of three times that volume of helium is 8 μmgrm. One quarter of this has entered the glass and has not escaped, hence the helium removed weighed 6 μmgrm. That number deducted from 716 leaves 710 μmgrm. as the weight of the niton.

To return for a moment to its volume. The amount of niton in the weighing-tube was 0·07347 cu. mm. at the moment of pumping out. But some niton had penetrated its walls, and was not removed by the pump. That amount was estimated by comparing the γ-radioactivity of the weighing-tube after it had been weighed "empty" with that of the gas pumped off, which had, of course, diminished in radioactivity; this diminution corresponded with the time which elapsed since the last reading, and was measured to verify the constancy of the electroscope. The radioactivity of the residue left in the weighing-tube was, after correction for natural leak, 17 divisions per hour. The original radioactivity of the niton in the weighing-tube was $3996 - 353 = 3643$ divisions per hour; its volume in the weighing-tube when decay commenced was 0·0887 cu. mm.; hence the "volume" left in the tube by the retention of niton in the walls was $(17 \times 0·0887)/3643 = 0·0005$ cu. mm. This, subtracted from 0·07347 cu. mm., the volume of niton in the tube at the moment of pumping out, leaves 0·0730 cu. mm. as the volume actually weighed.

All the data are now complete; 0·0730 cu. mm. of niton at 0° and 760 mm. pressure weighed 710 μmgrm. A litre weighs 9·727 grm.; a litre of oxygen weighs 1·429 grm.; and the molecular weight of niton is therefore **218.**

The nomenclature of Rutherford and Soddy, which has attained the provisional assent of the Brussels Congress, is advantageous as showing the relationship between the degradation-products of the various radioactive elements, but obscures any chemical relationship between the elements themselves. Were it consistently carried out, radium, which undoubtedly belongs to the group of alkaline-earth metals, would have to be named after uranium, a metal with no affinities with that group. The "emanation of radium" is a cumbrous name, and gives no indication of its position in the periodic table, a position which may now be taken as certain. To

show its relation to gases of the argon series, it should receive a similar name; and the spectrum, the freezing-point, the boiling-point, the critical point, the density of the liquid, and the density of the gas, the last establishing, without doubt, the atomic weight of the element, having been determined in this laboratory, it only remains to give it a name. The name "niton," Nt, which has been used in this paper, is suggested as sufficiently distinctive.

The research, of which the foregoing is an account, yields a further proof, if such were necessary, of the beautiful theory of the disintegration of the radioactive elements originally advanced by Rutherford and Soddy in 1902. The determination of the density of a gas, even with approximate exactness, has always been regarded as establishing its molecular weight, the accurate value of which may have been derived from other considerations. In the present case, these considerations are the result of the disintegration theory. Determinations by Madame Curie and by Thorpe of the atomic weight of radium show beyond all doubt that it differs little from 222·4. That four atoms of helium separate from one atom of radium is rendered almost certain from the work of Dewar, and from experiments by Rutherford, and by Ramsay and Soddy. That three atoms of helium are lost by niton on decay has been shown in the preceding pages. It follows that one helium atom must escape when radium changes into its emanation; hence the true atomic weight of the emanation must be 222·4. This number hardly differs from the mean of the atomic weight determinations given in this paper; and the disintegration theory receives a further confirmation.